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# Preliminary Definition and Evaluation of Advanced Space Concepts

## Volume I: Executive Summary

Prepared by
I. Bekey
Advanced Orbital Systems Division

30 June 1978

Prepared for
OFFICE OF SPACE TRANSPORTATION SYSTEMS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

Contract No. NASW-3030

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Prepared

I. Bekey, Director
Advanced Space System Studies

Approved

Samuel M. Tennant
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Advanced Orbital Systems Division

## FOREWORD

This report documents the results of a study performed under NASA Contract NASW-3030 during FY 77-78 by The Aerospace Corporation. Mr. Ivan Bekey was the Study Director and Principal Investigator. The study was performed under the technical direction of Mr. Donald Saxton, Advanced Programs, NASA Marshall Space Flight Center. Mr. J. vonPuttkamer, NASA Headquarters, Office of Space Transportation Systems, was the overall Program Manager.

The report is issued in two volumes. Volume I contains the Executive Summary. Volume II contains the full analyses and results of the study as well as appendixes and ancillary data.

A number of inputs were obtained during the study from people in various agencies and institutions, and some members of industry. Even though an attempt was made to reflect those inputs, the assumptions, numbers, views, and conclusions of the study are solely those of the author.

The characteristics, performance, and cost numbers derived in this study represent a "first cut," and were generated without any attempt at optimization. They should be viewed as very preliminary, and will undoubtedly change with further analysis.

## ACKNOWLEDGEMENTS

This report is the product of many minds. Their contributions are hereby gratefully acknowledged.

Satellite/Transponder Analysis and System Analysis - S. Lewinter

Wrist Radio Set Analysis — R. J. Meyer

Onboard Switch Analysis and Design — D. Theiss, L. Katzin

Antenna Analysis and Design - C. Coulbourn, J. Murphy, and L. Cantafio

Satellite Design - D. Cooley, G. Yee, and F. K. Hawkins

Intermodulation Analysis - D. Martin

Propulsion Analysis and Definition - J. Russi

Control System Analysis - G. Iwanaga

Graphics Coordination - R. Johnson

Acknowledgement is also made of the help of Mr. C. Tiffany, Mr. R. Guest, and Mr. J. McQuillan of AT&T Long-Lines and Government Operations who kindly provided data on the likely configuration and user charges of the telephone networks in the 1990 time period, which were used in costing and analyzing terrestrial alternatives to the space concepts.

In addition, a special thanks is extended to Mrs. J. Antrim for her invaluable support throughout the project, in preparation of many of the graphics, and in typing and shepherding the presentation and this report. It would not have been possible without her.

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# 1. INTRODUCTION

## 1.1 BACKGROUND

This study is the third in a sequence of investigations into advanced space system concepts performed by The Aerospace Corporation under contract to the NASA Office of Space Transportation Systems begun in 1975. The first in the series of studies was the identification of a large number of concepts (over 100) that appeared to have high potential for utility, depended on advanced technology and the availability and use of the Space Shuttle, and might be fielded in the 1980-2000 time period (Ref. 1). This set of initiative concepts - together with those identified by the NASA Outlook for Space Study - both performed in parallel in 1976, constituted a rich set of options for constructing an advanced space plan for the next two decades.

The second in the series of studies identified a set of development plans for groups of these initiatives to obtain a better understanding of possible program evolution as follow-on to the then-just-issued NASA 5-year plans, as well as to identify needed growth in the Space Transportation and Orbital Support Systems in that time period (Ref. 2).

This study represents the third step in which a few of the most promising initiatives identified initially, and grouped into development plans in the second study, are analyzed in more depth. First, to derive more confident numbers on their potential performance and characteristics; and second, to compare their performance and cost against leading terrestrial alternatives designed for the same requirements in order to evaluate their potential merits and utility.

Most of the more attractive initiatives identified in these past works took advantage of the complexity inversion phenomenon, in which the ability to service larger numbers of users with smaller and less expensive user equipment and deliver lower priced services, is made possible by deliberately making the satellites larger, more complex, heavier, and therefore more costly. The operation of these satellites in synchronous orbit, however,

enables a single satellite (or at most a few) to provide services directly to thousands or millions of users. Thus, the total system costs usually favor increasing the size of the satellite inasmuch as the differential cost savings thereby made possible in the terminals greatly exceeds the increased cost of the satellite. Furthermore, a number of services are thus made possible which simply cannot be provided with smaller satellites.

Examples of these include (as an extreme) - the provision of personal and emergency communications to very large numbers of citizens wearing wrist-sized terminals, electronic mail distribution to home terminals, distribution of TV programs directly to homes or schools, mass library and data bank exchange by small users, small business tele-conferencing as a means to save travel expenses and time, readout of very large numbers of small and inexpensive ground sensors for applications as diverse as freight tracking and prevention of undetected hijacking of nuclear powerplant fuel shipments.

A number of optical applications also exist - such as detecting forest fires by large optical heat detection systems in synchronous orbit, coastal zone monitoring for fishing violations, and the observation of creep along large numbers of points along fault zones for earthquake prediction. The latter is another example of complexity inversion in which the satellite would have a complex laser, however the ground units would consist of simple corner reflectors, proliferated at very low cost.

It is examples such as the above that aroused an enthusiasm among both lay and technical audiences over the past two years, since the first study on advanced concepts was made public. As a result of the report, numerous presentations on its contents, and presentations by other people on results of similar studies and analyses, an atmosphere is being created in which advanced technology satellites designed for earth-oriented applications are viewed with increasing favor by the Congress and many people as representing fruitful expenditures of public funds. Simultaneously, a number of social and institutional questions have been triggered, which are beginning to be asked

in public forums. This is a very healthy sign, inasmuch as technologists can at best hope to stimulate debate on the desirability of new applications while removing from such debates uncertainties about cost, availability, and performance of the potential systems. Thus, the motivation behind this study was to perform a definitive first analysis that contributes such data.

## 1.2 PURPOSE

The purpose of this study was to develop the characteristics, cost, and performance of a few of the more attractive application concepts, and to compare them against leading terrestrial alternatives, in order to determine their potential, identify those deserving further NASA attention and possible inclusion into the formal development planning sequence, and serve to initiate a dialogue with the using community and agencies.

## 1.3 APPROACH

The approach followed in this study was to select a maximum of three initiative concepts for detailed analysis from the hundreds identified previously; to specify a set of requirements against which the initiative design could proceed based on an interpretation of the needs of the using community; to perform preliminary designs of the initiatives using the desired set of requirements, iterating the requirements as necessary to keep the evolving systems feasible yet challenging; to identify leading terrestrial alternatives to each of the space initiatives which are capable of performing the same functions and meet the same requirements; to perform a one-to-one cost comparison of the space and ground concepts; and thus to draw conclusions on the advantages and disadvantages of the alternative space and ground solutions of the same problems.

At the outset, it was decided that only objective measures such as cost and performance would be quantitatively compared, and not the more subjective areas of benefits, social risks, institutional impact, regulatory agency attitudes, or the general desirability or appeal of the potential concepts. Although these more subjective measures clearly represent key issues that must be addressed prior to any commitment to proceed into

serious design and development of s h system concepts, it was felt such subjective analyses were beyond the resources of this study. Thus, this study was geared solely to provide technological and cost inputs that could be then supplied to those addressing the more subjective issues.

Both the space and user equipment segments were defined in the performance of this study, and a development plan was developed for each initiative. The general flow of the study is described by Figure 1.

## 1.4 CONTACTS/DOCUMENTS

After the initial set of initiatives to be defined were selected, a number of data-gathering trips and telephone contacts were made. Discussions were held with various agency and organization personnel in order to ascertain what might be a reasonable set of requirements against which to design the initiative systems and general alternatives. People who furnished

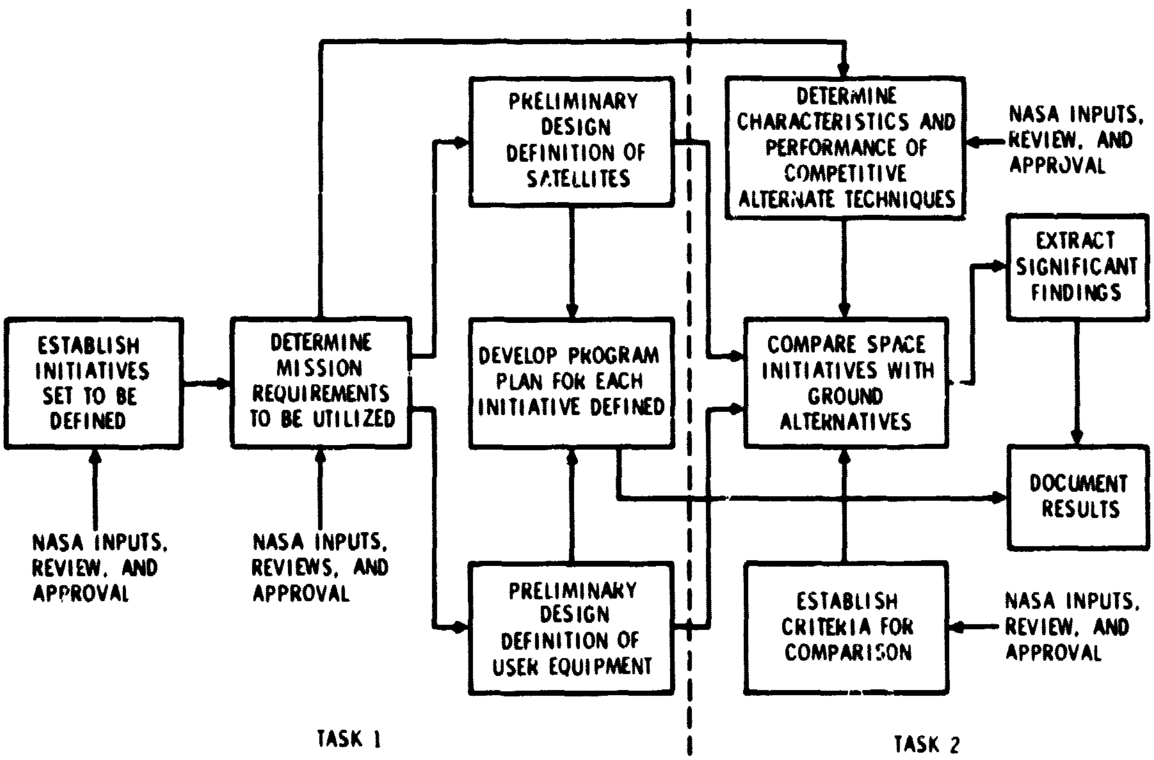


Figure 1. Functional Study Description

inputs and thoughts regarding useful functions and probable needs of the using community included the following:

| | |
|---|---|
| U.S. Postal Service | Mr. Ralph Marcotte |
| Public Broadcasting System | Mr. Dan Wells |
| Corporation for Public Broadcasting | Mr. Brian Brightly |
| National Institute of Education | Dr. Richard Otte |
| Appalachian Regional Commission | Mr. Robert Shuman |
| Joint Council on Educational Television | Mr. Frank Norwood |
| Public Service Satellite Consortium | Mr. John Witherspoon and Dr. James Potter |

In addition, discussions and numbers regarding the telephone networks in the 1990 time period were contributed by:

| | |
|---|---|
| American Telephone and Telegraph Co. | Messrs. Curran Tiffany, Jim McQuillan, and Robert Guest |

## 1.5 REFERENCES


1. I. Bekey, H. L. Mayer, and M. G. Wolfe, Advanced Space System Concepts and Their Orbital Support Needs (1980-2000), ATR-76(7365)-1, The Aerospace Corp., El Segundo, Calif. (Apr 1976).

2. Integrated Planning Support Functions (Study 2.7), ATR-77(7378)-1, The Aerospace Corp., El Segundo, Calif. (June 1977).

## 2. SELECTION OF INITIATIVES

A number of new initiative concepts were identified from the previous works at the outset of the study as potential candidates for further analysis and comparison with terrestrial alternatives. They are shown in Table 1. These candidates were then evaluated and ranked, then three were selected that appeared to have the most potential, a ready market, a degree of apparent user acceptance, appeared to require large satellites (thus conforming with the complexity inversion principle), had fewer hazards associated with their use, might be available in the 1985-1990 time period, had apparent credible terrestrial alternatives for which data were likely to be available, and for which the technology was sufficiently understood that performance and cost could probably be calculated. The selected initiatives and their functions appear in Table 2. They consist of an Electronic Mail concept to link government and industry buildings, an Educational Television system to distribute programs to all U.S. schools, and a Personal Communications system to link vast numbers of users with wrist radios for emergency, pleasure, and business uses. An additional initiative was selected to be analyzed if time and resources permitted, and that was the provision of rural telephone services directly through a single satellite. It was initially hoped that this initiative could be treated as a first step toward the Personal Communications capability, however, it was not possible to address it due to the limitations in resources and time.

**Table 1. Major Candidate Initiatives**

MOBILE COMMUNICATIONS

- PERSONAL/EMERGENCY COMMUNICATIONS
- PACKAGE/VEHICLE LOCATOR
- AIR TRAFFIC CONTROL

FIXED COMMUNICATIONS

- ELECTRONIC MAIL (HOME-HOME)
- VIDEO TELECONFERENCING
- RURAL EDUCATIONAL TV

REMOTE SENSING

- FOREST FIRE DETECTION
- 200-MILE LIMIT MONITORING
- EARTHQUAKE FAULT MOVEMENT

**Table 2. Selected Initiatives**

| INITIATIVE | FUNCTION |
|---|---|
| • Personal Communications | – Interconnection of Wrist Radio Personal Terminals<br>– Pleasure, Business, Mobile Uses<br>– Emergency Channels For:<br>Panic<br>Search/Rescue<br>Disasters |
| • Educational TV | – Program Dissemination and Interchange Within All School Systems In CONUS<br>– Open University Learning Center Program Distribution/Interaction<br>– Public TV Interconnect? |
| • Electronic Mail | – Interconnection of Business and Government Buildings Directly |
| • Rural Telephones | – To Be Defined If Time Permits |

## 3. DETERMINATION OF REQUIREMENTS

A set of requirements for the performance of the selected initiatives was derived after discussions with a number of people in various agencies and institutions, as discussed in Section 1. These requirements, which appear in summary form in Table 3, were derived with the intent to serve very large populations and numbers of users, and thus tackle much larger jobs than had been attempted previously. It is apparent from this table that the system designs must be very ambitious, inasmuch as the aim of the Personal Communications System was set at interconnection of 25 million people wearing wrist radio-telephones, which is 10 percent of the expected

Table 3. Initiatives Definition and Evaluation System Requirement Specifications

| REQUIREMENTS | PERSONAL COMMUNICATIONS (WRIST RADIO) | EDUCATIONAL TV | ELECTRONIC MAIL |
|---|---|---|---|
| Number of Users | 25 Million (10% of 1990 Population) | {165,000 Schools / 16,000 Districts / 4,000 Univ. and Colleges} or 250,000 Learning Sites | 544,000 Terminals (174,000 Business Offices / 370,000 Government Offices) |
| Location of Users | 2/3 Urban<br>1/3 Rural | {50 Studios} or {500 Stations} | Corporation Headquarters and Major Field Offices<br>All Gov't Office Buildings |
| Mobility of Users | Mobile | Fixed/Transportable | Fixed |
| Information | Voice | Color TV/2-Way Voice | Letters, Data, and Graphics |
| User Antenna Size | Wrist Set | 3 ft for Schools<br>10 ft for Districts | 3 ft |
| Access Time | < 1 min - non peak hrs<br>< 5 min - peak hrs | 1 hr/Day/District (Avg. Shared Channel) | 1 hr Typical<br>10 hr Maximum |
| Use Time | > 5 Uses/Day<br>1 min Minimum/Use | 24 hr/Day | 10 hr/Day<br>260 Days/yr |
| Terminal Life | 16 hr Before Recharging | N/A | N/A |
| Terminal Cost Goals | < $30 | < $300 Plus TV | < $1000 - Small Users<br>< $10,000 - Large Users |
| Safety Considerations | Power Density $< 10^{-4}$ W/cm$^2$ At 10 cm | N/A | N/A |

1990 population of the United States. The aim of the Educational Television system was set as equally ambitious, interconnecting all 65,000 U.S. schools and their 16,000 School District Headquarters (or all 4000 Universities and Colleges with 250,000 remote learning sites) with color TV and interactive audio using just small antennas on each school and district building. The aims for the Electronic Mail system were set as complete exchanges of "mail" between business and government, resulting in the daily interchange of an expected 15 billion pieces of mail per year (about 15% of the total mail flow) between 544,000 small terminals, each on a separate office building.

It is not claimed that these requirements are unique or sanctioned by the user community, however, they do represent an attempt to meet substantially all of the National needs foreseen for each class of application. The meeting of these requirements could result in social and institutional impacts. It was felt that to be most useful, this study should address systems capable enough to elicit such questions, inasmuch as their desirability in terms of long-term National goals could then be openly debated with some factual information at hand.

# 4. INITIATIVE SYSTEM DESIGN

The system requirements shown in Table 3 were used as the input to three preliminary design activities in which both the satellite and ground segments were defined, and their characteristics and performance derived. A summary description of the systems so evolved is briefly described.

## 4.1 PERSONAL COMMUNICATIONS SYSTEM

The Personal Communications initiative system concept, illustrated in Figure 2, utilizes a single large comsat to link large numbers of users with wrist radio-telephones.

Due to the small power and antenna size available in a wrist radio, the satellite antenna must be large and all channels demodulated to baseband.

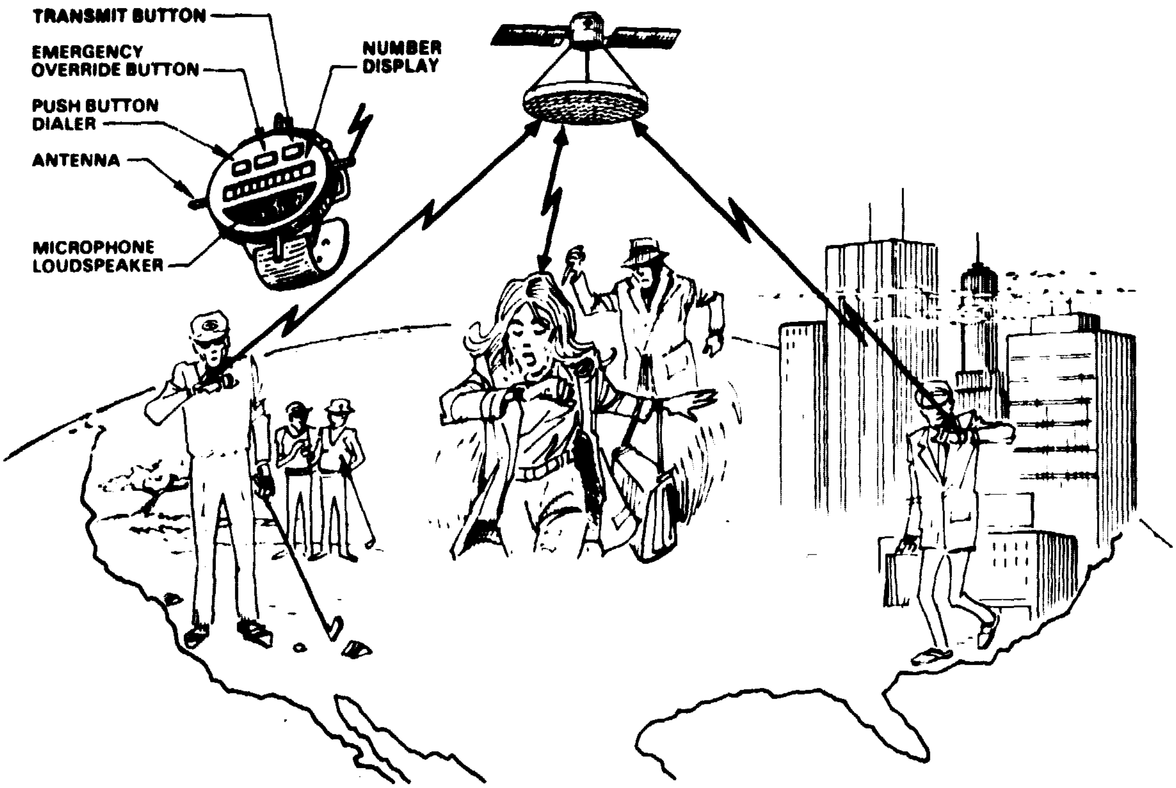


Figure 2. Personal Communications

Due to the large number of users, the satellite total radiated power must be large, and an onboard switch at baseband provided.

A simplified block diagram of the satellite appears in Figure 3. The design features a 67-meter diameter multibeam antenna, generating almost 7000 simultaneous spot footprint beams and 7000 independent transponders with 230, 000 simultaneous voice channels, switching among them from "caller" to "callee" by an onboard telephone-like switching exchange. The system covers all 48 contiguous United States completely in overlapping ellipses with minor and major axes about 30 by 60 miles.

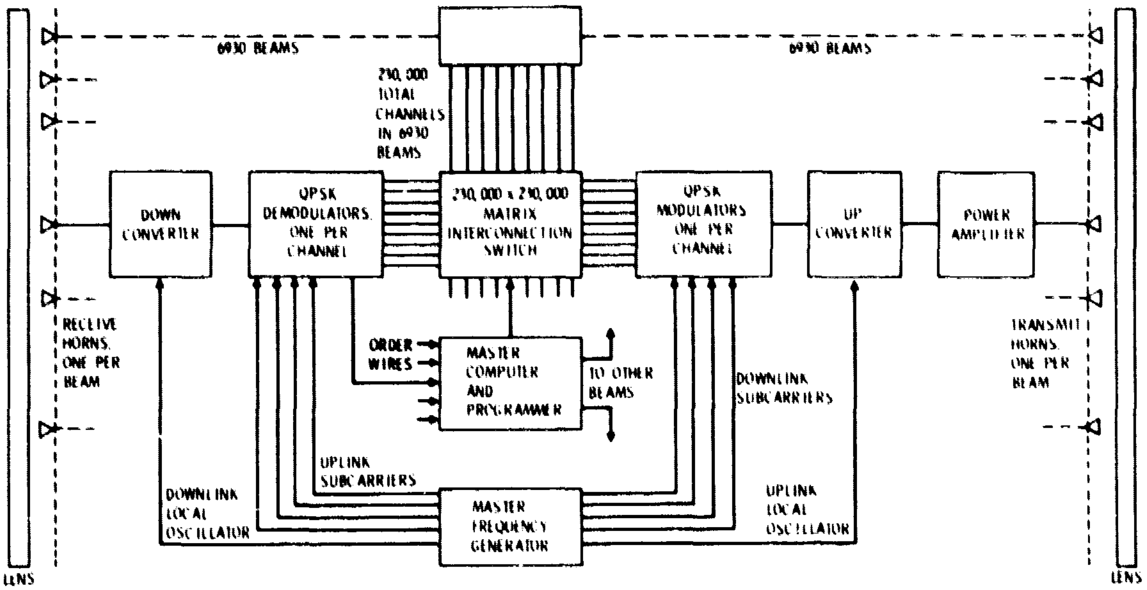


Figure 3. Simplified Satellite Block Diagram

The total bandwidth occupied is only 60 MHz at the operating frequencies in the 4.7 and 4.9 GHz bands, even though the satellite throughput is equivalent to 2300 MHz of bandwidth, due to the frequency reuse of the multibeam antenna. The frequency band suggested was chosen as it is currently lightly loaded, though almost any band from 1 to 7 GHz could be used.

The satellite transponders have 46 kW of total RF output power though the highest single transponder power is 380 W. The onboard switching system handles the full 230, 000 voice channels, and was designed based on scaling the Bell System No. 4 ESS and using anticipated 1987 wafer-scale integration technology. The switch requires 50 kW of power, and is all digital. The prime power system consists of solar arrays and batteries sized to deliver 210 kW at beginning of life in geostationary orbit, but was oversized to 287 kW to allow for the expected degradation during slow self-powered ascent from low orbit using its own ion thrusters. These thrusters then double for on-orbit attitude control and stationkeeping. The satellite is estimated to weigh 54, 000 lb and to have an IOC of 1990, preceeded by two development steps to be discussed later. The major system characteristics are summarized in Table 4.

Table 4. Major System Characteristics, Personal/ Emergency Communications

SPACE SEGMENT

- Single Satellite in GEO
- Antenna: 67 m (220 ft) dia; 6930 Beams; Footprint 30 x 60 mi each
- Transponders: 6930 Independent; 380 watts each Maximum
- Channels: 230,000
- Frequencies: Downlinks = 4.8-4.86 GHz; Uplinks = 4.40-4.46 GHz
- Bandwidth: 10 MHz per Beam Maximum; 60 MHz total
- Power: 46 kW RF, 273 kW Prime; Solar Cells
- Switch: 230,000 x 230,000 TDM Digital, Non-Blocking
- Propulsion: Self-Powered Ascent to GEO Using Ion Engines
- Weight: 54,000 lb Total
- Deployable, Assembled in LEO from Three Shuttle Launches
- Modular, Space Serviceable

USER SEGMENT

- Wrist Radiotelephone Set - 25,000,000 Users
- Access: 1 min Every 5 min During Peak Hours
- Voice Bandwidth, 2-Way Sets
- Antenna: Self-Contained Stubs or Slot
- Transmitter: 0.25 watt
- Battery Capacity: For Five Transmissions/Day - Recharge Overnight

The 25 million users would time-share the available channels under control of the satellite processor in a channel assignment scheme to prevent interference. Emergency messages would be given override priority. User charges would be based on length of messages, and administered through the mail or telephone bill via a ground station. The user terminal set looks like a wristwatch and radiates 1/4 W. Communications is expected to be as effective between users at 3 miles away as at 3, 000 miles away, with the same costs per minute of conversation.

The wrist radio-telephones would contain 1 micro-electronic chip, a battery measuring about 0. 25 in. on a side, a stub-crossed dipole or self-contained cavity-backed slot antenna, LED displays, and a number of controls. They are expected to weigh no more than a large wristwatch, and be able to communicate at least five 1-min messages during any 16-hr day before recharging overnight. The radiation level from the microwave transmitter would be two orders of magnitude below that required by the U.S. Standard for body absorption of radiation. A mock-up of the wrist radio-telephone is shown in Figure 4. It is expected that such radios could be mass produced to sell at retail outlets for less than $10. 00, using current prices for electronic digital wristwatches as an analogy.

A layout of the satellite is shown in Figure 5. It is expected that three shuttle flights would be required to take the satellite into low orbit, assemble it, check it out, and get it ready for its transfer to synchronous altitude. Transfer would utilize its own self-contained ion thrusters and its own power supply, taking about one year for the journey.

A development plan for the Personal Communications initiative is shown in Figure 6 in which a 4-step development program is recommended. The elements of the plan demonstrate the principle, the concept, the technology, and then the system in sequential orbital steps, with each demonstration step resulting in a useful operational capability, thus avoiding dead-ended hardware and providing return on the investment of each development step. An IOC of 1990 is envisioned for the final satellite if the total program

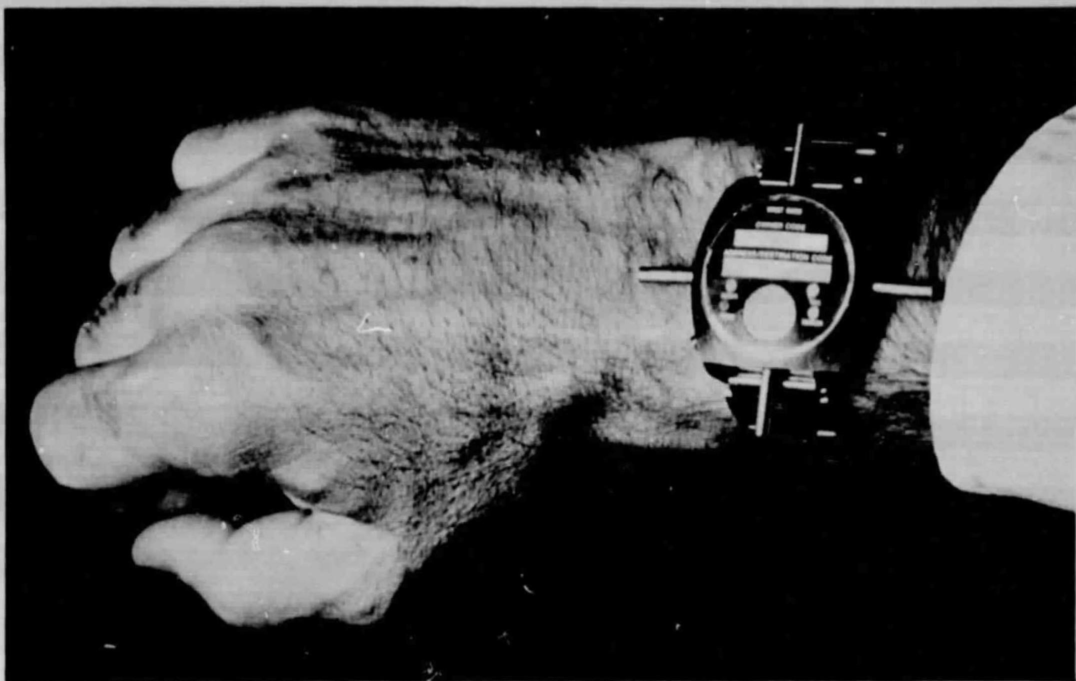

Figure 4. Wrist Radio-Telephone

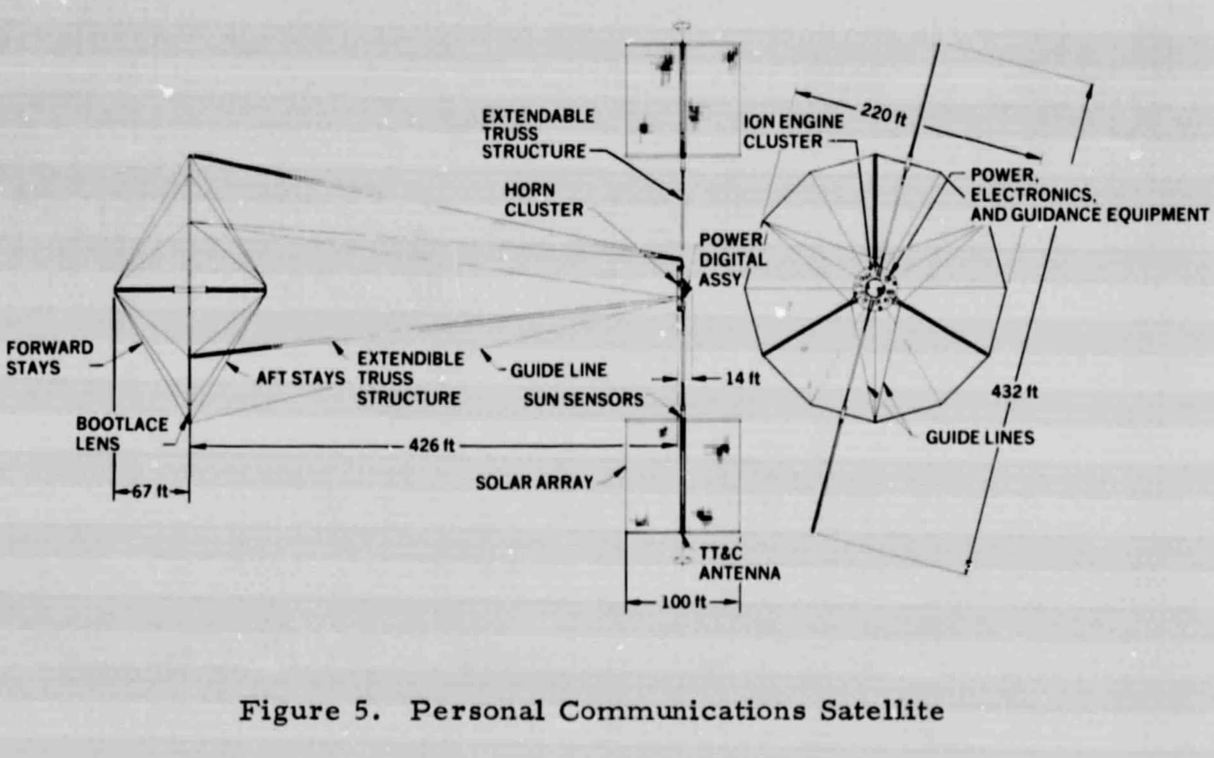


Figure 5. Personal Communications Satellite

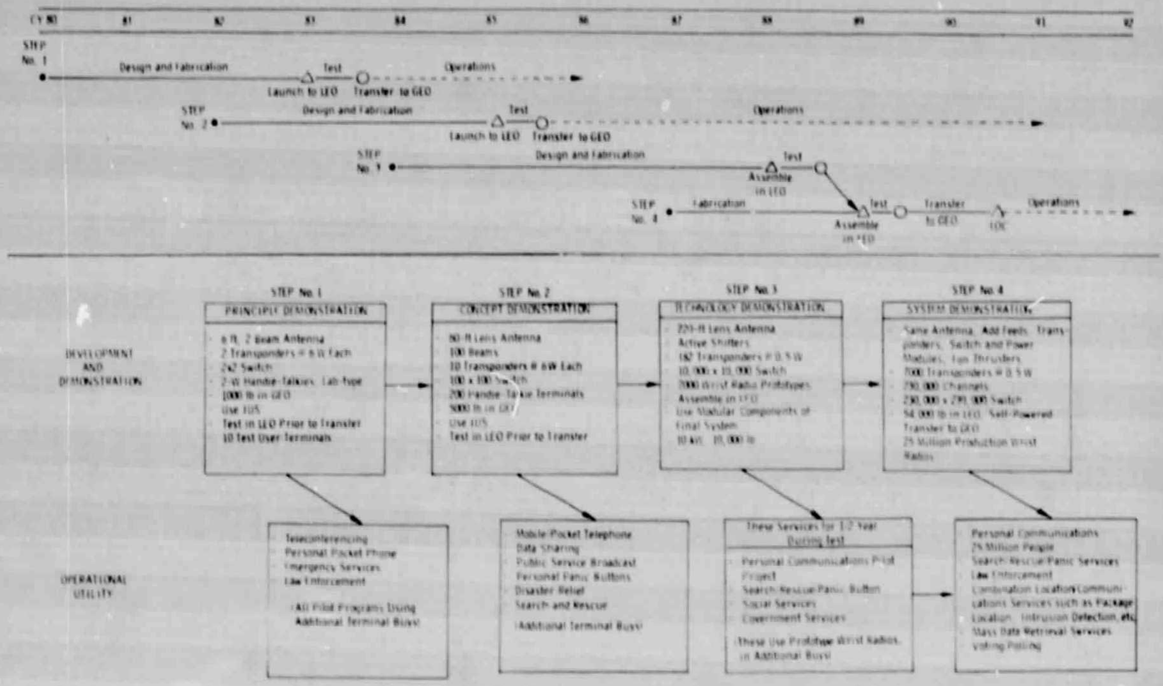


Figure 6. Development Plan for Personal/Emergency Communications Initiative

is begun in 1980. It is envisioned that the final satellite would be assembled in two steps. The full sized antenna and about 10 percent of the electronic and power components would be assembled in low orbit and checked out in the first step, and upon successful operation, mated in the second step with the rest of the electronics, power equipment, and the ion thruster units. Following checkout, the satellite would then be raised under its own power to synchronous altitude and placed into operation.

## 4.2 EDUCATIONAL TELEVISION SYSTEM

The Educational Television system initiative design, illustrated in Figure 7, also incorporates a multibeam lens antenna, multiple transponders, and onboard baseband switching; however, it was chosen to operate in the 20 and 30 GHz bands primarily because of the large bandwidth requirements and ready availability of allocations.

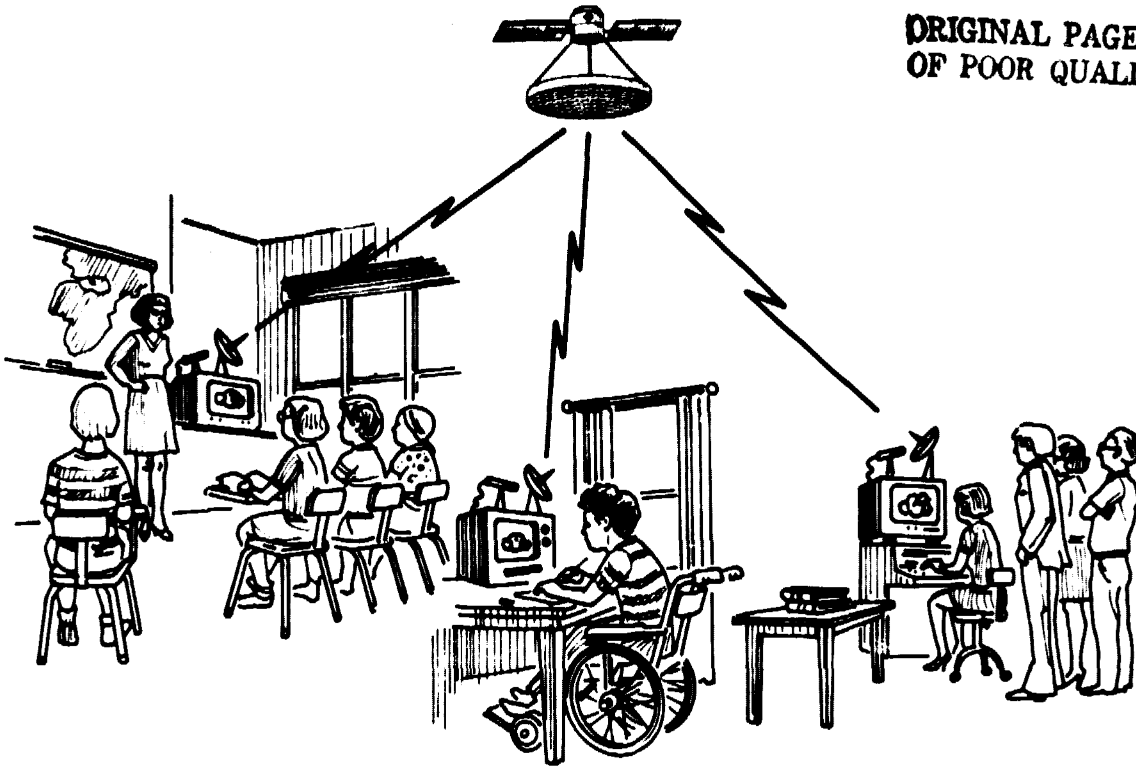

Figure 7. Advanced Educational TV

The satellite antenna diameter of 9 1/2 meters allows color-TV reception using earth stations with 3-ft fixed antennas on the schools, and two-way TV communications by the School Districts using 10-ft tracking antennas. A block diagram of the satellite is shown in Figure 8. Almost 1500 TV channels are transmitted simultaneously in 600 beams, each covering an area of 50 by 100 mi on the ground, centered on populated areas within the contiguous U.S. In addition, 634 simultaneous uplink TV channels are available from the Districts for program origination. Complete freedom of connectivity is established by onboard switching so any District can broadcast programs to its schools, to other District schools, nationwide broadcast, or other inbetween options. In addition, any 10 percent of the 16,000 Districts can interchange or share 10 percent of their program libraries in real time through the satellite. The satellite is expected to radiate a total of 10 kW of RF,

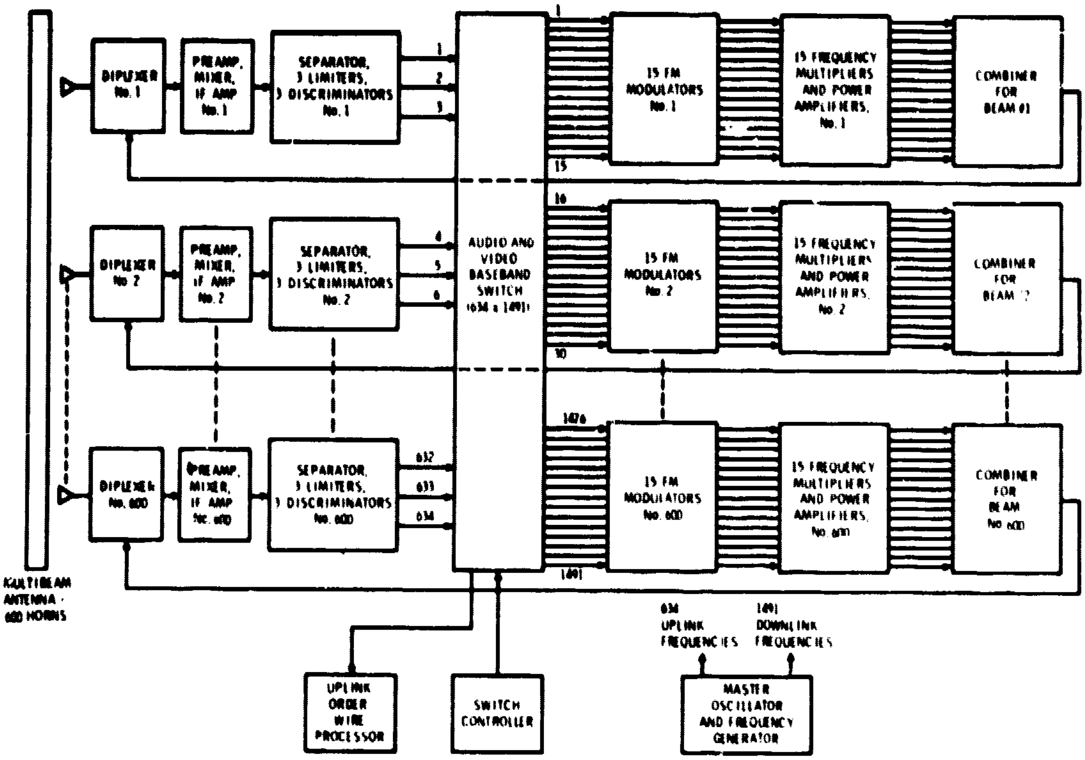


Figure 8. Educational TV Satellite Block Diagram

though no transponder will have more than 180 W of power. The 600 transponders contain demodulators and modulators so that all channels are switched at baseband. The onboard switch is a 634 by 1491 port crosspoint diode switch. The power source is solar cell arrays that will generate 63 kW at beginning of life in low o 50 kW at beginning of life in geostationary orbit following a 1/2-yr s powered ascent using its own ion engines. Conventional hydrazine thrusters are used for attitude control and stationkeeping. The satellite is expected to weigh just under 10,000 lb, and be assembled in low altitude orbit from a single space shuttle flight.

The schools would be outfitted with 3-ft dia fixed antenna terminals and the School Districts with 10-ft dia auto-tracking antennas with 6-W transmitters. The terminals would be desk-top sized. A video recorder would be used in conjunction with the District terminal, and a distribution panel would be used in each school to patch TV monitors and microphones into the required classrooms in each school.

The characteristics of the system are briefly summarized in Table 5. A layout of the satellite is shown in Figure 9 in which a man is shown for scale comparison only. The satellite is seen to be not much larger than today's satellites.

A development plan for the Educational TV satellite is shown in Figure 10. This plan, as the one for the Personal Communications initiative, uses a number of steps of increasing complexity, each paced by reasonalbe technological progress in a well-funded deliberate program. Each step accomplishes an orbital demonstration and also serves an operational purpose to avoid dead-ended hardware. An eight-year period is envisioned from start to the operational capability established by the final satellite. The full-sized satellite is assembled in two steps, with the final antenna and about 10 percent of the electronics being assembled in the first step. After checkout the rest of the components would be mated and checked out prior to self-powered transfer to synchronous altitude.

Table 5. Educational TV Major System Characteristics

**SATELLITE SEGMENT**

- Single Satellite in GEO
- Antenna: 9.6-m dia; 600 Beams; Footprint - 50 x 100 mi Each
- Transponders: 600 Independent; 15 Watts Each, Solid State
- Frequencies: Downlinks - 19.7 - 21.0 GHz; Uplinks - 29.5 - 30.8 GHz
- Bandwidth: 540 MHz per Beam; 1620 MHz Total
- Power: 15 kW RF, 65 kW Prime - Solar Cells
- Switch: 634 x 1491 Crosspoint Pin Diode Type
- Propulsion: Self-Powered Ascent to Geostationary Using Ion Engines
- Weight - 9800 lb Total
- Deployable fro Single Shuttle Launch
- Modular Space Serviceable

**USER SEGMENT**

**@ 16,000 DISTRICT HEADQUARTERS**

- Antenna: 10-ft Autotrack
- Transmitter: 6 Watts
- 3-12 Channels TV
- Video Cassette Recorder/Player
- Interactive 2-Way Audio
- Total Capacity: 1491 TV Channels Distributed

**@ 65,000 SCHOOLS**

- Antenna: 3-ft Fixed
- Receive Only
- 1-12 Channels TV
- Distribution Panel
- 10 TV Monitors/School (average)

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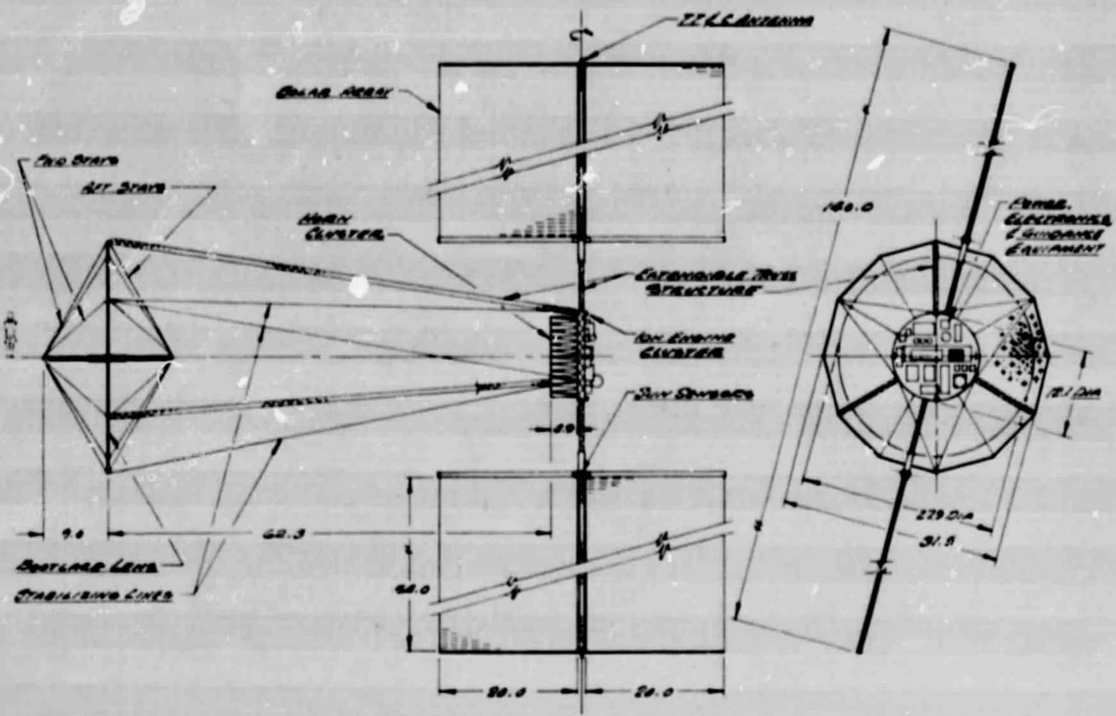

Figure 9. Educational Television Satellite

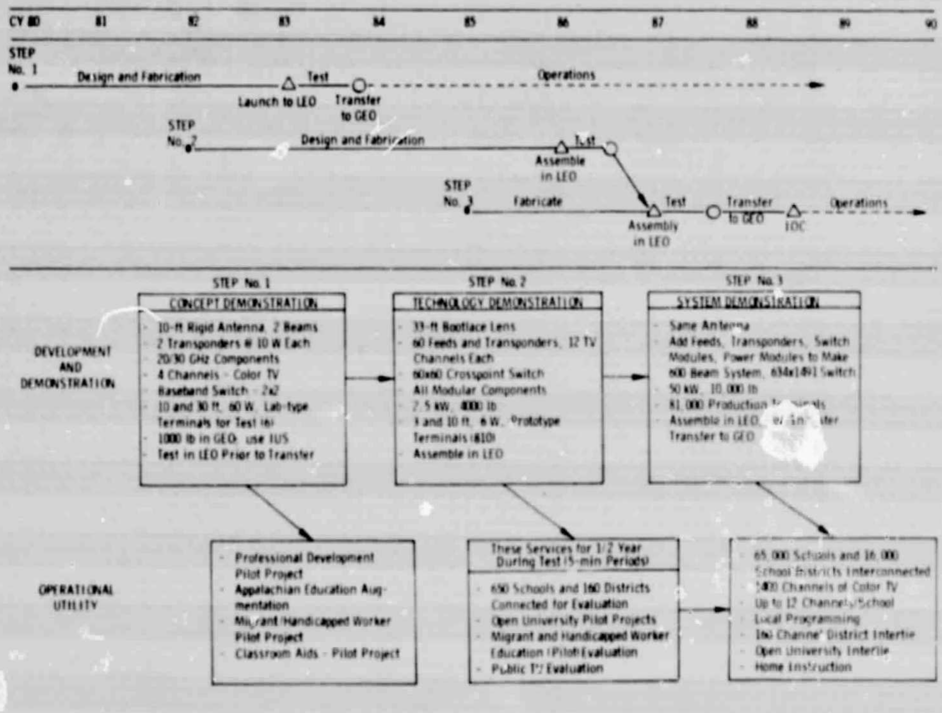


Figure 10. Development Plan for Educational TV Initiative

## 4.3 ELECTRONIC MAIL SYSTEM

The Electronic Mail system concept, illustrated in Figure 11, resulted in a satellite similar to the Educational TV design, incorporating a multibeam lens with the same aperture also operating at 20 and 30 GHz. The frequency selection was based on the non-real time requirements of mail delivery which make rain outages tolerable, and ready frequency allocations. The 540,000 user terminals are outfitted with 3-ft dia fixed antennas and 6-W transmitters on the roofs of user buildings, and are located within 846 spots generated by 846 beams, whose footprint measures about 50 by 100 mi dia each. All the terminals within one beam footprint share the same channel in a time division multiple access scheme in which each user has a time slot. Thus, all such users communicate "mail" with each other directly through one satellite transponder by using and recognizing addressor/addressee coded transmissions. The satellite employs an onboard store-and-forward buffer processor

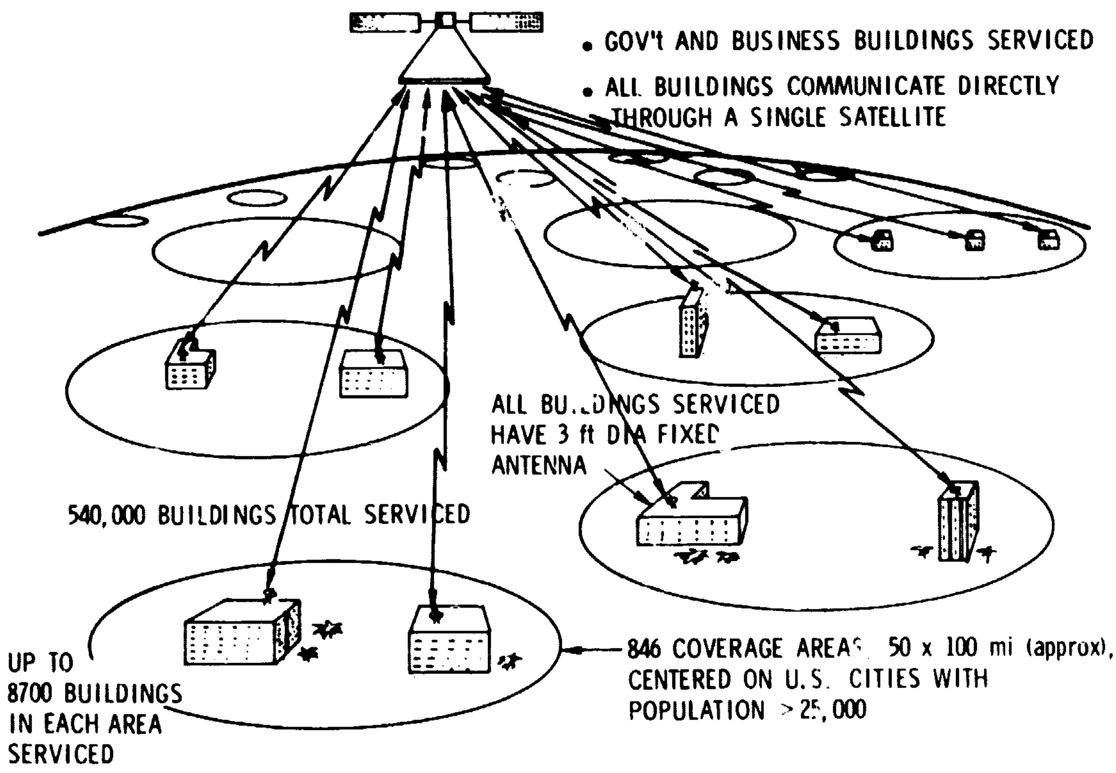


Figure 11. Electronic Mail Satellite Concept

with 846 bins which allows all users not in the same beam to communicate "mail" with each other.

The block diagram of the satellite, shown in Figure 12, illustrates the 846 parallel transponders and buffer/processor. The bandwidth of any one beam/transponder is 12 MHz or less, and the total RF spectrum occuppied by the system is 75 MHz, due to extensive frequency reuse. The total RF satellite power is 2.5 kW, though no one transponder requires more than 3W. The prime power required is 13 kW at beginning of life in low orbit, and 10 kW at beginning of life in synchronous orbit, the satellite being transferred to synchronous altitude using its own ion thrusters and power supply. The satellite would be stabilized on-orbit by a small hydrazine altitude control system. It would weigh 5300 lb and be assembled in low orbit from a single space shuttle launch.

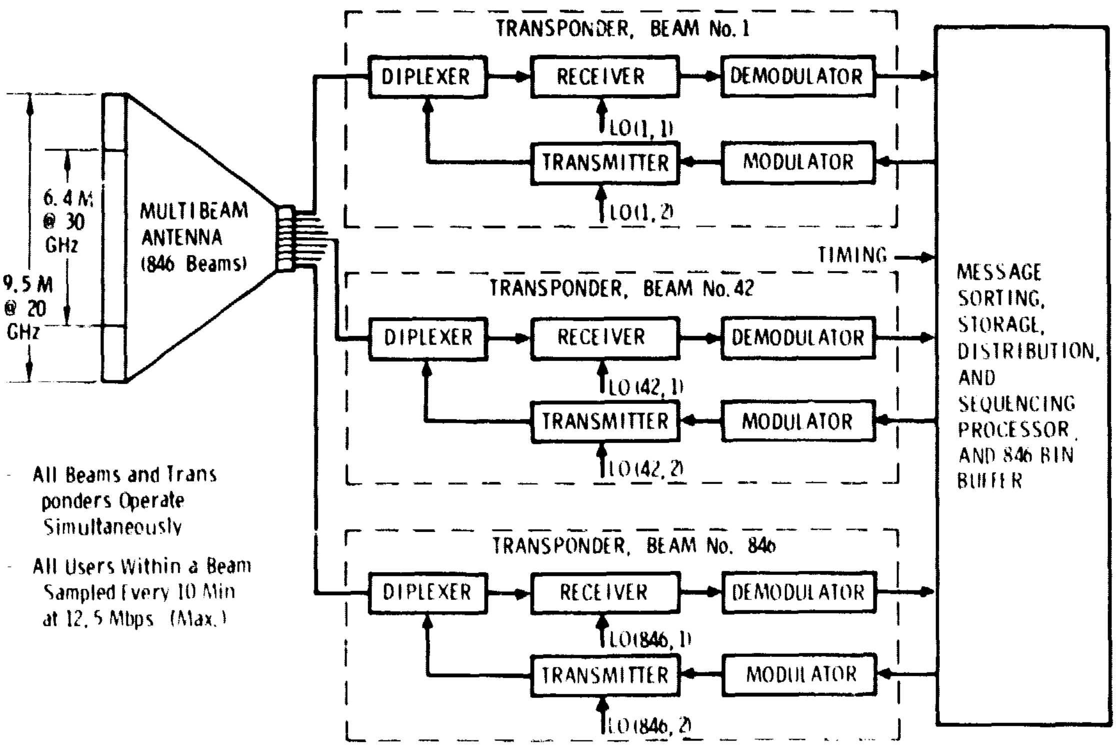


Figure 12. Electronic Mail Satellite System Block Diagram

The system characteristics ar. summarized in Table 6, and a layout of the satellite is shown in Figure 13.

The Electronic Mail terminals would be built in three or four sizes, varying from table-top size for the 470,000 smallest users requiring only a 300-bps data rate, to a large console for the 5700 largest users needing a 40-kbps data rate. Facsimile machines would be used for the input and output devices at every terminal, very similar to today's commercially available units which operate over a phone line and transfer one page every 2 to 6 minutes. Two facsimile units would be required in each terminal, or one unit capable of both reading and printing operations sequentially. The "mail" would be exchanged between all units on the average of once every 10 min, but not less than once every day.

Table 6. Electronic Mail Major System Characteristics

SATELLITE SEGMENT

- Single Satellite in GEO
- Antenna: 9.6-m dia; 846 Beams; Footprint • 5 x 100 mi each
- Transponders: 846 Independent; 3 watts each; Solid State
- Frequencies: Downlinks • 20.0-20.1 GHz; Uplinks • 29.5 - 29.6 GHz
- Bandwidth: 12 MHz Maximum per Beam; 75 MHz Total Up and Down
- Power: 2.5 kW RF; 13 kW Prime - Solar Cells
- Switch: All Digital 846 Channel Store-and-Forward; 400 lb
- Propulsion: Self-Powered Ascent to Geostationary Using Ion Engines
- Weight: 5300 lb Total
- Deployable from Single Shuttle Launch
- Modular Space Serviceable

USER SEGMENT

- Antenna: 3-ft dia, Fixed
- Transceiver: 6.3 watt Transmitter; Uncooled Receiver
- Bandwidth: 12 MHz Maximum
- All Users Sampled Every 10 Minutes
- Buffer Store for 10 Min Mail Volume
- Smallest Terminals
  - 472,000
  - 4 min/page Fax Machines
  - 22 Letters/Day

  Largest Terminals
  - 5,700
  - 4 page/min Fax Machines
  - 1800 Letters/Day
- Total Capacity: 15 Billion Letters/Year

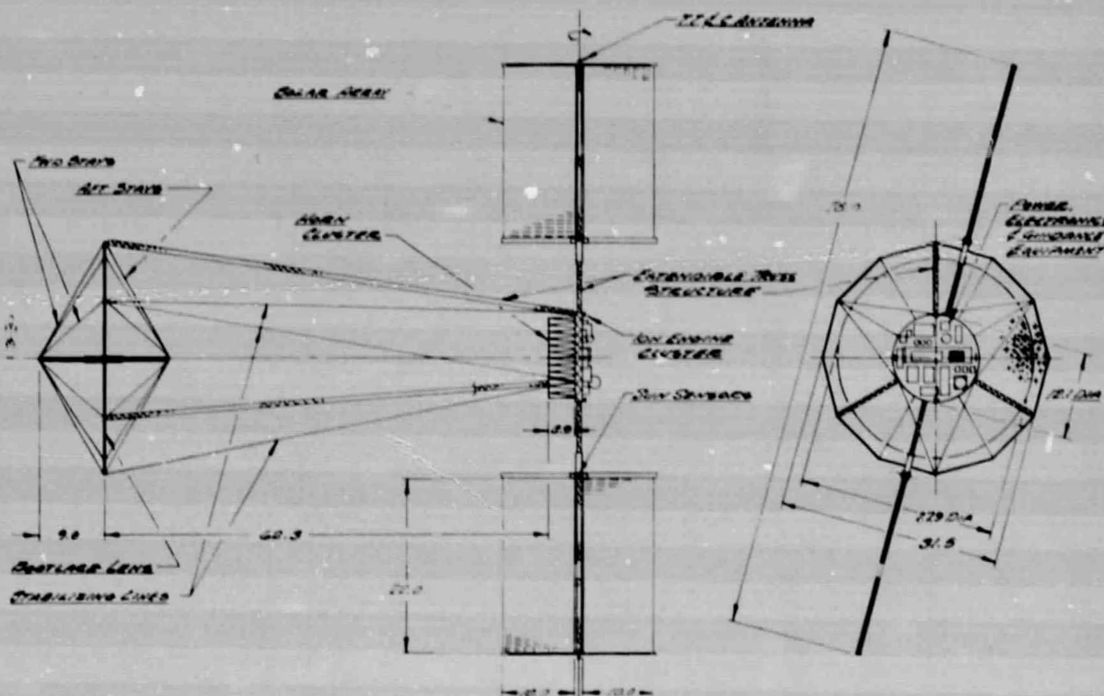

Figure 13. Electronic Mail Satellite

The development plan for the Electronic Mail initiative is shown in Figure 14. This, as the previous development plans, is a step-wise approach assuring no dead-ended hardware by so configuring the test articles that operational configuration and useful services will result from each step. As previously, the final satellite is put up in two steps with the final antenna and 10 percent of the electronics comprising the first step.

## 4.4 INITIATIVE CONCEPT SUMMARIES

The major characteristics of all three initiative designs are summarized in Table 7 and of the terminals in Table 8. The satellites are very powerful, more so than any yet launched, though the product of their transmitter power and antenna gain (EIRP) is equal to or less than that predicted for the state of the art in the 1987-1990 time period as shown in the projections of Figure 15.

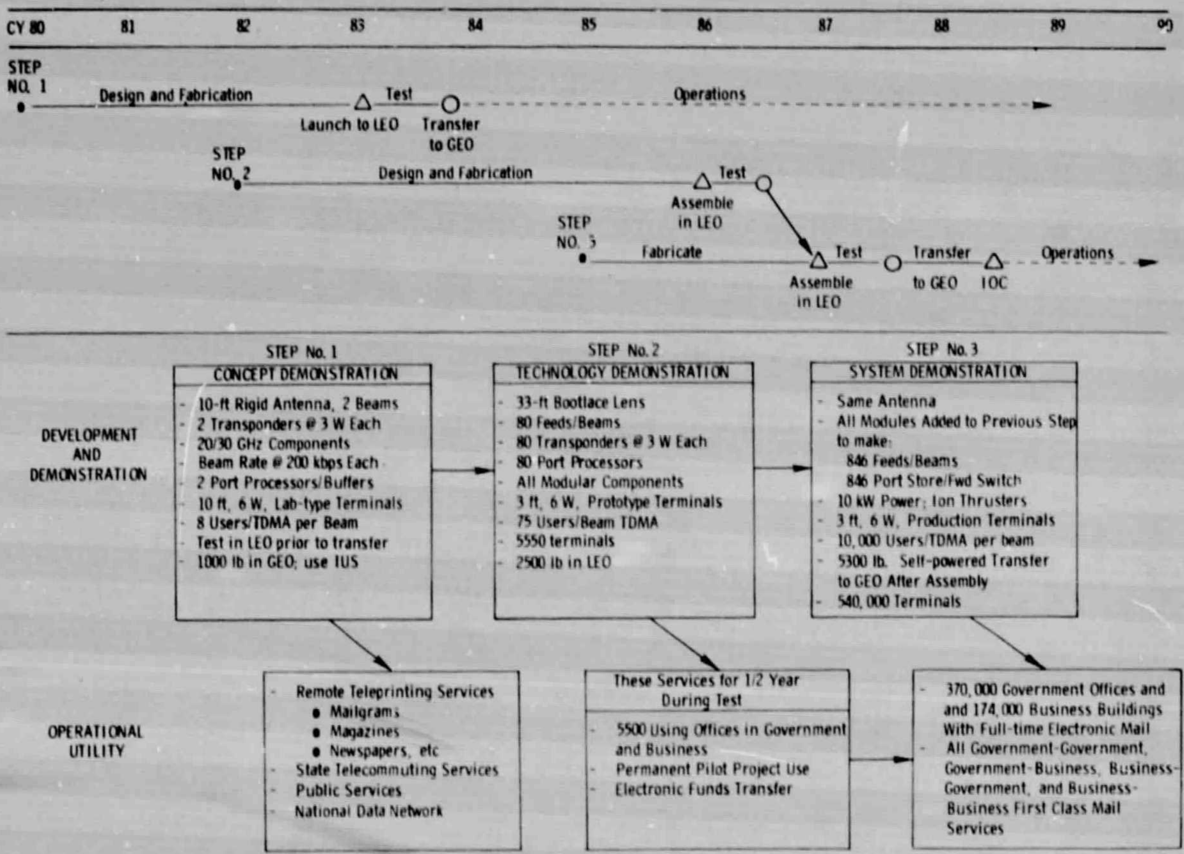


Figure 14. Development Plan for Electronic Mail Initiative

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## Table 7. Initiatives Definition and Evaluation System Design Summary

| SYSTEM ELEMENT | DESIGN PARAMETER | | PERSONAL COMMUNICATIONS | EDUCATIONAL TV | | ELECTRONIC MAIL |
|---|---|---|---|---|---|---|
| SPACE TERMINAL | ANTENNA TYPE | | Multi-Beam Lens | Multi-Beam Lens | | Multi-Beam Lens |
| | ANTENNA DIAMETER | | 67 M (220 ft) | 9.5 M | | 9.5 M |
| | FREQUENCY | Downlink<br>Uplink | 4.80-4.86 GHz<br>4.40-4.46 GHz | 19.7-21.0 GHz<br>29.5-30.8 GHz | | 20.0-20.1 GHz<br>29.5-29.6 GHz |
| | BANDWIDTH | | 60 MHz | 1.3 GHz | | 75 MHz |
| | FOOTPRINT/COVERAGE | | 30 x 60 Miles, All CONUS | 50 x 100 Miles, 600 Spots | | 50 x 100 Miles, 846 Spots |
| | NUMBER OF BEAMS | | 6930 | 600 | | 846 |
| | NUMBER OF CHANNELS | | 230,000 | 1491 Down<br>634 Up | | 846 |
| | POWER LEVEL | RF<br>System - BOL | 46 kW<br>273 kW (est.) | 10 kW<br>63 kW | | 2.5 kW<br>13 kW |
| | WEIGHT | | 54,000 lb | 9,800 lb | | 5,300 lb |
| GROUND TERMINAL | ANTENNA SIZE | | Wrist Set | 3 ft Fixed | 10 ft Tracking | 3 ft Fixed |
| | POWER LEVEL | | 0.25 W | N/A | 6 W | 6 W |

## Table 8. Terminals

| TYPE | | PERSONAL COMMUNICATION | EDUCATIONAL TV | | ELECTRONIC MAIL | | |
|---|---|---|---|---|---|---|---|
| | | | DISTRICTS | SCHOOLS | SMALL USERS | MID-SIZE USERS | LARGE USERS |
| NUMBER | | 25,000,000 | 16,000 | 65,000 | 470,000 | 60,000 | 6,000 |
| TYPE | | Wrist Unit | Desk Top | Desk Top | Table Top | Small Console | Large Console |
| ANTENNA | | Self-Contained | 10-ft Dia Autotrack | 3-ft Dia Fixed | 3-ft Dia Fixed | 3-ft Dia Fixed | 3-ft Dia Fixed |
| RECEIVER | FREQ. GHz | 4.7 - 4.76 GHz | 19.7 - 21.0 GHz | 19.7 - 21.0 GHz | 20 - 20.1 GHz | 20 - 20.1 GHz | 20 - 20.1 GHz |
| | G/T (db/°K) | -27 | 21.6 | 11.6 | 11.6 | 11.6 | 11.6 |
| TRANSMITTER | FREQ. GHz | 4.9 - 4.96 GHz | 29.5 - 30.8 GHz | 29.5 - 30.8 GHz | 29.5 - 29.6 GHz | 29.5 - 29.6 GHz | 29.5 - 29.6 GHz |
| | POWER (W) | 0.25 | 6 | N/A | 6 | 6 | 6 |
| PROCESSOR/BUFFER | | 1 Chip | N/A | N/A | $3 \times 10^5$ bits | $3 \times 10^6$ bits | $2 \times 10^7$ bits |
| PERIPHERALS | TYPE | N/A | Video Recorder | N/A | - Reader/Printer (FAX) | - Reader/Printer (FAX) | - Reader<br>- Printer<br>- FAX |
| | SPEED | N/A | STD | N/A | 4 min/page | 1 min/page | 0.25 min/page |

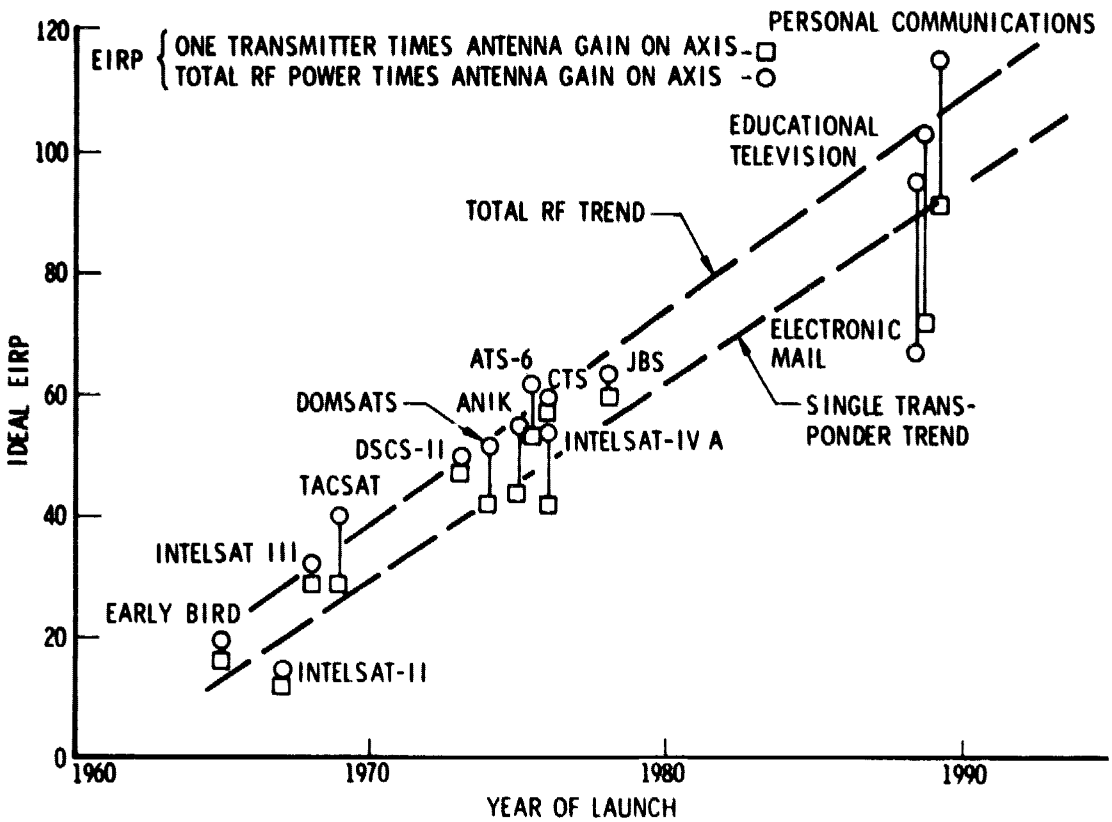


Figure 15. Ideal EIRP of Communications Satellites

## 5. TERRESTRIAL ALTERNATIVE CONCEPTS

Terrestrial alternatives to the three space systems described in Section 4 were defined for the same set of requirements, and to the same performance levels so that a one-to-one comparison of their costs could be made. These alternative concepts are shown in Table 9. They were configured using data about the likely configuration of the telephone networks per discussions with AT&T.

The terrestrial alternative chosen for the personal communications system is comprised of a large number of towers with radio relay equipment, which is used to connect the wrist radios to the telephone networks, which in turn provide the interconnection and the switching required for system

Table 9. Competing Systems Initiative Definition and Evaluation

| OPERATIONAL DATE | SPACE ALTERNATIVES | | TERRESTRIAL ALTERNATIVES | |
|---|---|---|---|---|
| | SYSTEM | PACING TECHNOLOGY | SYSTEM | PACING TECHNOLOGY |
| 1990 | Personal Communications (Wrist Radio) | Large Antenna Switch Complex Electronics | Line-of-Sight to Tower. Towers Interconnected Using the Telephone Networks | Wrist Unit Integration |
| 1989 | Educational TV | High Frequency Lens Antenna and Components | Point-to-Point Distribution via Fiber Optics and Coaxial Cable | Fiber Optics |
| 1988 | Electronic Mail | High Frequency Lens Antenna and Components | Point-to-Point Interconnection Using Telephone Networks | Inexpensive Facsimile Machine |

operations. The pacing technology for the terrestrial alternative is the integration of the wrist units, since the telephone networks will be configured to handle the calls in the 1988 time frame, while the pacing technology of the space alternative is the large antenna and complex switching in the satellite. The towers were assumed emplaced so as to cover all the U.S. contiguous areas, even though telephone line connections would not be available for those in the wilderness and unpopulated areas. Thus, the coverage expected would be less than that of the space system, though the population served would be essentially the same.

The most attractive terrestrial alternative to the Educational TV system was chosen with distribution of TV programs from districts to schools via an average of four coaxial cables per district, and program sharing between districts using fiber optic cables with 150 TV channel capacity. All switching would be done at the districts by order wire enabling of the proper channels, thus avoiding optical switching. The pacing technology is that of the fiber optics, whereas that for the satellite alternative is the high frequency lens antenna and its components. The performance of ground and space alternatives is equal.

The most attractive terrestrial alternative for Electronic Mail distribution was chosen with point-to-point interconnection of the buildings using the telephone networks. These networks would likely be able to provide all switched digital point-to-point services in the time period without augmentation. The pacing technology in this case would be inexpensive facsimile machines, whereas the pacing technology for the space alternative is the high frequency lens antenna and components.

# 6. SPACE/GROUND COMPARISON

An overall cost comparison was performed for the space and ground systems defined in Sections 4 and 5, in which they were configured to perform the same functions against the same requirements. The total costs were determined including all RDT&E equipments, all demonstration steps discussed in the development plans, all user equipment, the required control centers, and 10 years of operation of the final satellite including all orbital maintenance flights needed. Service charges by the telephone networks were included for the ground alternatives. These total costs were then divided by the user-relevant quantities in 10 years of operation to obtain costs per call for the Personal Communications system, costs per classroom-hour for the Educational TV system, and costs per letter for the Electronic Mail system.

The overall comparison is shown in Table 10.

Table 10. Overall Cost Comparison

| ALTERNATIVE | ELECTRONIC MAIL | EDUCATIONAL TV | PERSONAL/EMERGENCY COMMUNICATIONS |
|---|---|---|---|
| SPACE | 2.6 CENTS/LETTER | 0.36 $/CLASS HOUR | 0.7 CENTS/MIN |
| GROUND | 9.9-25.3 CENTS/LETTER | 1.78 $/CLASS HOUR | 20 CENTS/MIN |
| CURRENT SERVICES | 15 CENTS/LETTER (Stamps) | ≈10 $/CLASS HOUR (Teachers) | 13.3 CENTS/MIN (Telephones) |
| TOTAL COSTS OF SPACE SYSTEM INCLUDING RDT&E AND 10-yr OPERATIONS | 3.9 BILLION | 2.7 BILLION | 2.3 BILLION |
| TOTAL 10-yr INCOME (or savings) POSSIBLE IF SPACE SYSTEM IS BUILT AND OPERATED, BUT USERS CHARGED AT CURRENT SERVICE RATES | 23 BILLION | 73 BILLION | 48 BILLION |

- 1977 DOLLARS
- IOC 1988-1990

It is seen that in all cases the cost of the user services delivered by the space alternatives are considerably cheaper than that of the ground alternatives. Both ground and space alternatives for Electronic Mail and Educational TV are cheaper than the current services.

The Electronic Mail system is seen to be able to exchange mail directly to and from the 540,000 business and government users' buildings for 2.6 cents per "letter" as compared to the current 15 cents per letter of the U.S. Postal Service. The ground system configured in this study resulted in a 25-cent per letter cost; however, an alternative ground technique using regional distribution electronic centers, but retaining mail carriers, was analyzed by RCA for the U.S. Postal Service and concluded that 9.9 cents per letter is feasible. In addition to being more expensive, the current postal service is slower, since the space system alternative of this study exchanges mail on the average of every 10 min and at least once a day.

The Educational TV system can deliver quality color TV program distribution and establish two-way interactive audio with half of the classrooms in all schools in the United States for 36 cents per classroom hour, which compares with $1.78 per classroom hour for the competing ground system using a dedicated fiber optics network. Both ground and space alternatives include all TV receivers required, and appear considerably cheaper than the estimates for current program delivery via dedicated live teachers, while making a rich catalog of real-time and shared programs available. Provision of a tape library of 185,000 programs, 20 percent of which are updated every year, would increase those costs to 61 cents/hr and $2.04/hr, respectively -- still much less than live teachers.

The Personal and Emergency Communications system is able to connect 25 million people anywhere in the USA at anytime for a total charge of less than one penny per minute, as compared to the charges of the ground alternative of about 20 cents per minute and that of the current average of telephone service charges of about 13 cents per minute for a mix of local flat-rate and long distance toll charges (which are fixed and thus do not perform the same function but are shown for comparison purposes only). Furthermore, the ground and fixed alternatives do not cover all thinly populated areas for emergency services and contacting outdoor sportsmen, campers, and

people traveling in cars and trucks. However, the quality and length of the ground communications messages is expected to be greater than that of the space system.

The total costs of the space alternatives, also shown in Table 10, appear very high until it is remembered that they include all R&D demonstration flights, user equipment, and 10 yr of operation including required service flights. Furthermore, the costs for the ground systems are higher, being $38.5 billion for Electronic Mail - almost 10 times greater; $13.5 billion for Educational TV - almost 6 times higher; and $20.8 billion for Personal Communications, also almost 10 times higher than the space alternatives.

A different perspective might be useful on these cost comparisons. If the space systems were developed and operated, but the users charged at a rate comparable to today's user charges, the total 10-year income to the operating corporation or agency (or savings compared to current operations) is shown in the bottom on Table 10, and would be $23 billion with the Electronic Mail System; $73 billion with the Educational System; and $48 billion with the Personal and Emergency Communications System. Thus the profit would exceed 100 percent per year for all of these systems, with breakeven times of less than 2 1/2 years - numbers which are so impressive that it is hard to see how private industry could resist entering this marketplace.

## 7. CONCLUSIONS

A number of major conclusions were reached in this study. They are summarized in Table 11. It has been shown that all three of the space communications initiatives chosen for analyses appear to be technically viable for IOC in the 1987-1990 time period. In order of increasing technological difficulty and risk, they are: the Electronic Mail Initiative, the Educational Television Initiative, and the Personal Communications Initiative.

Table 11. Conclusions

1. ALL THREE COMMUNICATIONS INITIATIVES APPEAR VIABLE FOR IOC IN 1987-1990.
2. VERY LARGE CAPACITY SERVICES MADE POSSIBLE BY LARGE, COMPLEX SATELLITE AND MANY SMALL INEXPENSIVE USER TERMINALS.
3. ELECTRONIC MAIL IS THE LIGHTEST AND MOST STRAIGHTFORWARD SATELLITE WHILE PERSONAL COMMUNICATIONS IS THE LARGEST AND MOST COMPLEX.
4. NECESSARY DEVELOPMENT AND DEMONSTRATION FLIGHTS ALL RESULT IN OPERATIONAL UTILITY.
5. NO NEW OTV DEVELOPMENT REQUIRED.
6. DRAMATIC USER COST SAVINGS OR PROFITS ARE POSSIBLE COMPARED TO CURRENT SERVICES.
7. TERRESTRIAL ALTERNATIVES ARE LESS ATTRACTIVE BY A FACTOR OF 5 TO 30.
8. PROFIT POTENTIAL IS SO ATTRACTIVE THAT PRIVATE SECTOR DEVELOPMENT IS HIGHLY LIKELY AFTER TECHNOLOGY DEMONSTRATION.
9. SOCIAL/INSTITUTIONAL QUESTIONS ABOUND. ROLES OF VARIOUS AGENCIES AND INDUSTRY REQUIRE DEFINITION.
10. PROPER FREQUENCY ALLOCATIONS MUST BE PROTECTED IN GWARC-79.

Each of these initiative system concepts employs the complexity inversion phenomenon whereby new dimensions of services to very large numbers of users outfitted with very small and inexpensive user terminals are made possible by a single large, complex satellite in geostantionary orbit. It has been shown that at least one-half million Electronic Mail small terminals in user buildings can be interconnected through a single satellite, interchanging "mail" on the average of once every 10 min, but at least once a day. Every one of the 65,000 schools in the United States can receive Educational Television broadcasts with monitors in half of the classrooms, the programs originating in District or Board Headquarters. Almost 1500 simultaneous TV channels can be broadcast nationwide, with 150 channels of TV being available for long range interconnect between School Districts for program sharing or live program origination. In addition, 260,000 interactive voice channels can be provided, all with small terminals at each school and District. Twenty-five million citizens outfitted with $10 wristwatch-sized radio-telephones can communicate with each other through the Personal Communications satellite, with no interference and guaranteed access, for the same low cost regardless of distance - as effectively at 3 mi as at 3000 mi apart.

The required technology developments lie in the areas of large multibeam antennas, with very many simultaneous beams, transponders with demodulation/remodulation to baseband, onboard switching of many ports at baseband, high transmitted and prime power, and configurations designed for on-orbit servicing and attainment of high reliability.

In considering the development and demonstration of this technology, it was found that all the demonstration flights needed could result in useful operational capability, thereby avoiding dead-ended developments, and bringing in revenues that could be used to offset the costs of the development flights themselves.

It was found that due to the high onboard power required for these initiatives, efficient use can be made of selfcontained ion engines to effect

a self-powered transfer from the low-altitude orbits (where these satellites would be assembled by use of the space shuttle), to synchronous altitude where they will be operational. Thus, no new orbit transfer vehicle development is required for any of the initiatives, though if low thrust orbit transfer vehicles were developed for other purposes, they certainly could be used in these programs.

It has been shown that dramatic cost savings (or profits) are possible, utilizing the space initiatives compared to current services being provided. Furthermore, the leading terrestrial alternative concepts analyzed are more expensive than the space alternatives by a factor between 5 and 30. The overall cost comparison indicates that using the new space initiatives, "mail" can be sent at 2.6 cents per letter compared to the current 15 cents per letter of the U.S. Postal Service; that Educational TV can be disseminated at a cost of 36 cents per class-hour as compared to the approximate $10.00 per classroom hour necessary for teachers alone; and that Personal/Emergency communications can be provided at a call cost of less than 1 cent per minute, as compared to the average of local and long distance calls through current telephones of about 13 cents per minute.

In an inflating economy it is important to compare all the alternatives using inflated dollars. Furthermore, in comparing any options the use of present value discounted dollars is also useful. Both such comparisons were made, and the space concepts still came out way ahead of either the ground alternatives or of current services.

This study could only address three out of several dozen initiative concepts, many of which have a potential as attractive as the three selected, or even more so. Follow-on studies should examine these and other system concepts in at least equivalent depth.

It is likely that there is a very large profit potential for any corporation or consortium interested in pursuing these three applications and charging the users for the services provided. These applications could result in enormous savings compared to services at current rates, and/or

net profits measured in the billions of dollars per year might be realized while still undercutting current service costs and providing better services. Thus funding and development by the private sector could very well occur if only the high risk technology needed is demonstrated. The roles of government versus that of the private sector in demonstration of this technology and provision of these services needs to be addressed, as it has not been in this study.

It is possible that pressures to develop initiative system concepts such as these could appear soon. Thus, it is extremely important that the appropriate social and institutional questions raised by systems of this type be examined. These questions include those relating to job dislocation and retraining of people displaced by the introduction of the new services; the questions of how to address the introduction of these services so that they become extensions, rather than replacements, of current services and thereby avoid the great opposition that the latter would undoubtedly bring; the roles of government versus industry, and that of various agencies vis-a-vis themselves; and the very questions of what is progress and what kind of a society we wish to become should be raised when addressing these initiatives. This study could not do so, but it is highly recommended that follow-on studies do.

The very important question of protection of frequency and orbit space for services such as these must be addressed. It is quite likely that precursor systems, or systems having other applications, will come into being in orbit, operating at the same frequencies which these initiatives would require. These early systems will have very small capacity in terms of information delivered per bandwidth used, because they probably will not have the large scale frequency reuse capability of the multiple beam antennas used in these initiatives. Their presence will be fully justified on the basis of meeting early needs for a variety of public service communications, however their very existence could preclude the fielding of highly capable initiatives such as analyzed herein simply because the best frequency

bands are occupied. It would be tragic if we could not develop highly capable second generation systems because first generation systems with much less capacity enjoy squatters' rights on the orbit and frequency spaces required. Therefore, we must address the question of a mechanism by which we can phase-out earlier satellites before the end of their useful life in order to introduce more capable follow-ons. Who is to be compensated - by whom - and how much for the premature termination of such satellites' services?

A second question arises in this area, and that is of protection of the proper frequency and orbit spaces in anticipation of these extremely capable systems. Decisions will be made in GWARC-79 that could have a lasting effect for two decades. It would be tragic if GWARC-79 did not include at least a discussion on a proposal for deliberate protection of allocations compatible with these highly capable system initiatives.

A further comment concerns large geostationary platforms. Each of these three initiatives has been defined for independent operation. It is quite clear that many elements of these satellites appear very similar both in the antennas, transponders and the housekeeping subsystems. Thus, they could probably operate from a central platform furnishing housekeeping and structure to three payloads. The exact mechanization of how to best join these three services aboard a single platform requires definition. Such studies are desirable follow-ons to this study. The fact that the initiatives of this study were treated as separate satellites should not be construed as advocacy of single satellites or a criticism of multiple payload platforms.

Last, it must be said that none of the designs, costs, characteristics, performance, or any other attributes of the three system concepts evolved in this study should be considered as final or optimum in any sense of the word. They represent preliminary design concepts selected after little opportunity for deep tradeoff analyses, and in response to fairly arbitrary sets of self-imposed requirements whose sole purpose was to derive the

likely weight, performance, and cost of highly capable satellites of this type in this time period, performing these functions. Doubtless, many other configurations are possible and some might be considerably better in a number of attributes than the configurations found within. The requirements were set by the author after some discussions with the using community, but without opportunity for feedback. It is quite possible that a set of requirements has been used that is inappropriate for the first development item, or the time period, and more appropriate for a later one. Thus, follow-on studies should examine requirements, as well as the best system configuration, performance, characteristics, and costs to meet those requirements, inasmuch as these considerations were not possible due to the small scope of this study.

Above all, this information should be made freely accessible to the communities and agencies that would be involved with their use; and the social and institutional questions and their general desirability should be thoroughly aired in public forums.